Best Management Practices to Reduce Nitrate Impacts in Ground Water and to Assess Atrazine and Arsenic Concentrations in Private Water Wells

Project No.: 03-8

Final Report

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Texas AgriLIFE Extension Service
And
Texas AgriLIFE Research

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Executive Summary

Rural Texas relies almost entirely on groundwater for its domestic needs. The contamination of groundwater from nonpoint sources related to the production of food and fiber has been noted by the Texas Commission on Environmental Quality (TCEQ). Detections of atrazine and nitrates have been noted in water wells located in the Texas High Plains and Texas Rolling Plains. Producers and private water well owners gained information related to best management practices (BMPs) associated with agriculture production and wellhead protection designed to reduce the risk of nonpoint source contamination of groundwater.

This project was established and conducted to provide a field-level platform to demonstrate best management practices (BMPs) related to the management of nitrates by use of winter cover crops . Additionally, this project completed an assessment of the presence of atrazine, nitrate, and arsenic in private water well samples in the High Plains and Rolling Plains of Texas.

Results from the cover crops portion of this project found shoot biomass was the highest with cereal rye (4300 lb/a), followed by wheat (2500 lb/a) and no differences were observed between the vetch (540 lb/a) and the fallow (560 lb/a) treatments. In the fallow plots were some broadleaf and grass weeds were present, the estimated nitrogen per acre recycled was 17 lbs/a, while the vetch treatment was 20 lbs/a. However, the rye and wheat were significantly better at recycling nitrogen because of the large biomass produced. The cereal rye and wheat had accumulated over 110 and 75 lbs/a of nitrogen in their biomass.

A total of 135 samples were screened for atrazine and atrazine concentrations during this project. Additionally, 238 samples were screened for nitrate-nitrogen concentrations, as well as, salinity concentrations and the presence of fecal coliform. Samples were collected from seven counties in the Texas High Plains and Rolling Plains during 2005 and 2006. The results for atrazine revealed 87 samples with a concentration below 3.0 µg/L and 4 samples with concentrations above 3.0 µg/L. Regarding arsenic, 104 samples exhibited concentrations of zero µg/L, 30 samples fell into the 0 to 10 µg/L range, and 1 sample had a concentration of greater than 30 µg/L for arsenic. The average nitrate-nitrogen concentration for all samples was 2.7 mg/L and average salinity for all samples stood at 513 mg/L. Of the 238 samples screened for bacterial contamination, 92 or 38.7% of the samples were found positive for fecal coliform bacteria. These results would indicate that private wells face a much greater risk to bacterial contamination compared to chemical contamination from arsenic or atrazine or nutrient contamination from nitrate-nitrogen. Private wellowners received copies of screening results and educational information related to the program findings.

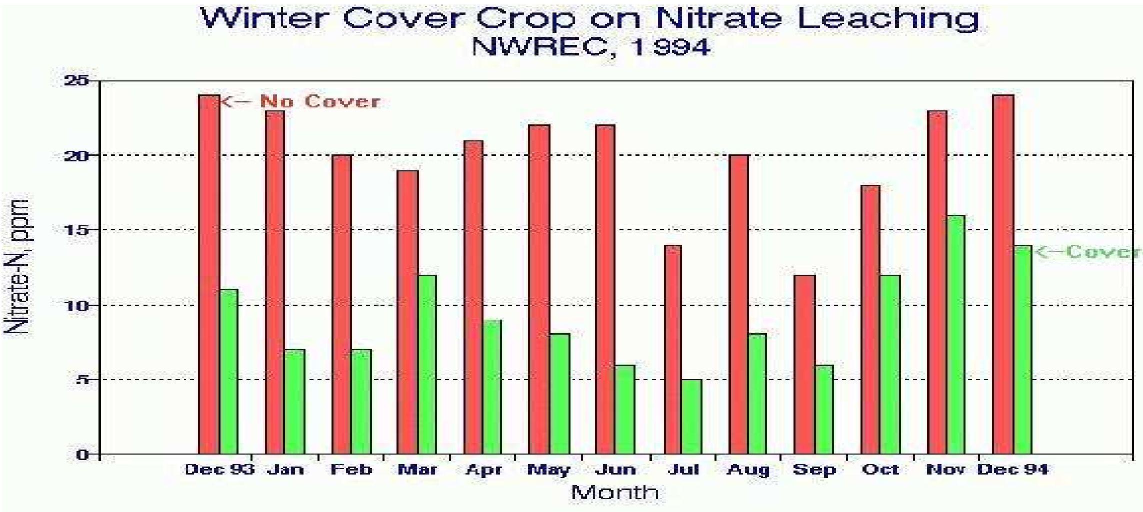
The zeolite portion of this project was dropped due to issues related to securing an acceptable and reliable supply of zeolite to conduct the demonstration work.

Project Introduction and Background:

Rural Texas relies almost entirely on groundwater for its domestic needs[1]. The contamination of groundwater from nonpoint sources related to the production of food and fiber has been noted by the Texas Commission on Environmental Quality (TCEQ[2]). Detections of atrazine and nitrates have been noted in water wells located in the Texas High Plains and Texas Rolling Plains[3]. Producers need to learn information related to best management practices (BMPs) associated with agriculture production designed to reduce the risk of nonpoint source contamination of groundwater.

One such BMP that can provide reductions in nitrate concentrations in soils is the use of a winter cover crop. In the past, cover crops were primarily planted to minimize soil loss from wind and water erosion. More recently the long-term benefits of cover crops for maintaining and improving soil characteristics, such as nutrient retention, aggregate stability, water holding capacity, organic matter, and nitrogen assimilation are being realized (Hussian et al., 1999[4]; Needleman et al., 1999[5]). The ability of cover crops to capture and recycle nitrogen and other nutrients reduces the potential for nonpoint source water pollution caused by nitrate leaching, soil erosion, and can reduce nitrogen fertilizer inputs (Meisinger et al., 1991[6]; Decker et al., 1994[7]; Duck and Tyler, 1996[8]).

Previous research has demonstrated a high potential for nitrate is loss in the winter, which are typically the highest precipitation months of the year in Texas. Winter cover crops minimize nitrate leaching by sequestering residual nitrate leftover from the summer crop. With a winter cover crop present, the nitrate can be mined from the soil by the cover crop roots prior to the nitrate leaching beyond the crop root zones. The nutrients, including nitrate, that are recycled by the winter cover crop are then available for the following summer crop. For example, rye cover crops have been reported to decrease in soil N of 143 lbs/acre during the wet months of December through April (Kavdir and Smucker, 1999[9]). Brandi-Dohrn et al., 1997[10] reported soil solution nitrate-N collected 4 feet beneath the soil surface to be approximately 50% less in cover crop plots compared to bare soil treatments (see Figure below). Additional organic matter is also added to the soil, which will increase water holding capacity and soil structure and conserves soil moisture.



The use of zeolite has been proposed as a method to reduce contaminate concentrations in water. However, very little work exists related to setting up a system to wellhead treatment of groundwater through a zeolite filter. If this filtering system proves effective, groundwater could be treated at the wellhead to reduce atrazine and arsenic concentrations before water enters the private water well distribution system.

Finally, there is a need to conduct water well screening events for private water well users related to nitrate, atrazine, and arsenic concentrations. Private water well users can make more informed decisions related to the use and management of their individual water resource when they have information related to potential contaminate concentrations.

Project Description:

In this project, Dr. Gaylon Morgan and Dr. John Sij will design and implement a cover crop demonstration. In this demonstration, three different winter cover crop will be planted and maintained as well as one winter fallow treatment. Porous cup samplers will be placed below each treatment to collect nitrate-nitrogen leaching through the soil profile. This leachate will be analyzed for nitrate-nitrogen concentrations. Soil samples will be taken at the beginning and end of the growing season to determine soil nitrate levels. Cover crop biomass samples will be taken prior to cover crop desiccation to determine the amount of nitrate-nitrogen assimilated by the crop. All information generated from this demonstration will be shared with agricultural producers at field days, CEU meetings, newsletters, and through a demonstration report.

The zeolite portion of this project will focus on determining the feasibility of using a zeolite filtering system to reduce atrazine and arsenic concentrations in groundwater. Groundwater samples of a known concentration will be filtered through a filtering device packed with zeolite and the concentration of the filtered water determined. From this information, the percent reductions in initial atrazine and arsenic reductions will be determined. All analysis will be done using a field-level Hach kit and immunoassay kit.

For the assessment portion of this project, a total of 50 samples will be collected during three annual private water screening days conducted in the High Plains and Rolling Plains of Texas.

Project Objectives:

The objectives of this project included:

- determination of the amount of leachable nitrate that can be removed from the soil profile by winter cover crops,
- demonstration of the percent reduction in atrazine and arsenic concentrations in water by use of zeolite filtering media, and
- assessment of nitrate, atrazine and arsenic concentrations in private water well samples of the Texas High and Rolling Plains.

Task 1: Removal of Nitrate from Soil Profile with Winter Cover Crops.

The field research portion of this project was initiated in the fall of 2005 and was completed in the spring of 2008. The treatments for the cover crop demonstration include three different winter cover crops that were planted and maintained as well as fallow treatment. The winter cover crops were planted with a small plot research grain drill and the drill rows were on 7.5” centers. See Figure 1. Each cover crop was planted according to the recommended seeding rate and planting depth. After planting the cover crops, a 2” augur was used to collect soil samples down to 3’ in one foot increments. See Figure 2. In the 2005-06 and 2006-07 seasons, the deep soil samples were composited across the entire study. In the 2007-08 season, soil samples were collected from each plot. The soil sample holes were then used as the hole for the porous cup samplers. See Figure 3. The ceramic cup at the bottom of the porous cup samplers were placed at a depth of 3’ in each plot. To insure good contact between the porous cup sampler and the native soil, a slurry of deionize water and the soil were mixed and poured into the hole. Native soil was used to finish filling the area above the porous cup samplers. The final step in the installation was pulling a vacuum on each sampler and sealing each hose to hold the vacuum pressure. We returned to the site at least 24 hours after installation to evacuate any water that had accumulated in the samplers from the slurry. A vacuum of 30 psi was pulled on each sampler again until the first water sample was taken monthly or after each major rainfall event. However, due to various circumstances such as drought, no water samples were ever taken from the porous cup samplers.

Figure 1. Planting winter cover crops at Vernon, TX 2007

Figure 2. Tractor with hydraulic probe that was used for collecting preseason and postseason soil samples.

Figure 3. Picture of a porous cup sampler prior to installing the sampler to a 3 ft depth in Haskell, TX 2005.

Winter cover crop treatments, which included cereal rye, wheat, vetch, and fallow, were planted each year in the fall. In 2005 and 2006, the winter cover crops were drilled into cotton stubble with a Hege' conventional tillage planter and a Great No-till planter, respectively. The cover crops were planted and marginal stands were obtained in the fall; however, following emergence sufficient precipitation did not occur to accumulate any measurable biomass. The no-till drill and timely precipitation was very beneficial in stand establishment in the cotton stubble. Good stands and biomass accumulation was occurring in the winter when the farmer accidently applied ammonium nitrate over the research plots while fertilizing the entire field. See Figures 4 and 5. So, this location was abandoned. In 2007-08, Dr. Sij and Dr. Dozier decided to initiate this trial in a more controlled environment at the Texas AgriLife Research and Extension Center in Vernon. However, in 2007 the cover crops were planted into a prepared seedbed and followed a forage sorghum crop. In the fall of 2007, the cover crops were planted into adequate moisture for crop establishment. However, following the cover crop planting less than ½" of precipitation occurred until mid-February. Despite the drought conditions average biomass was accumulation occurred in the wheat and rye cover crops. In the fallow treatment, weeds were not removed from the treatment; however, very little biomass accumulated in these treatments. See Figures 6 and 7. All treatments were hand clipped at the soil surface from a 3 ft^2 area within each plot. These biomass samples were oven dried within 48 hours of harvest. Oven dried samples were sent to the Texas AgriLife Extension Service Soil, Water, and Forage Testing Laboratory in College Station, TX. Nutrient analysis for each sample was quantified.

Figure 4. View of the wheat and rye plots at Haskell, TX 2006-07.

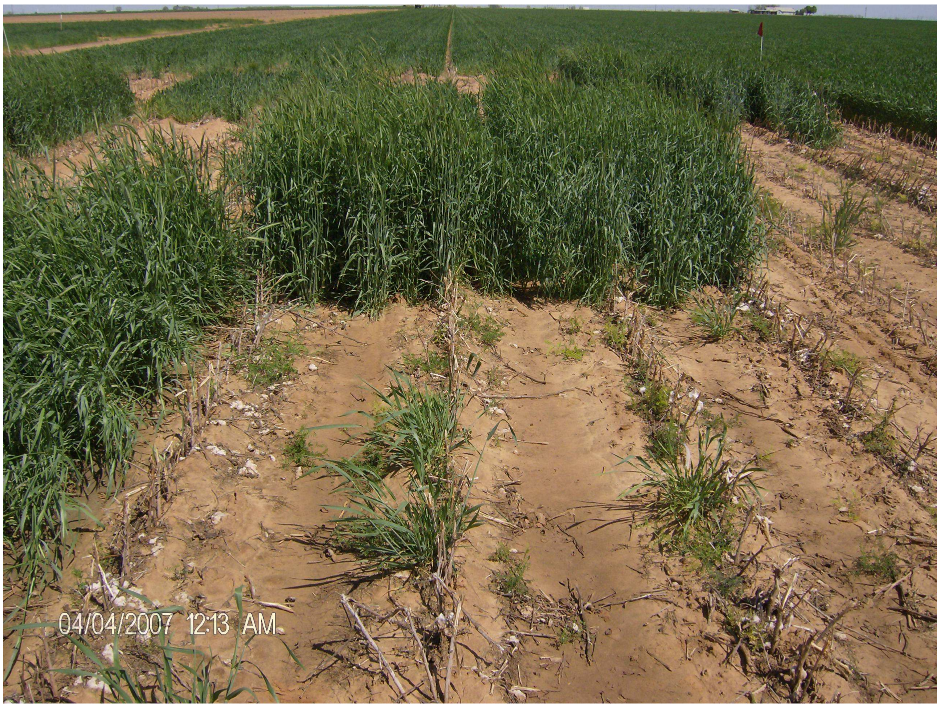


Figure 5. Vvetch and rye in the foreground and background, respectively, at Haskell in 2006-07.


Figure 6. Harvesting of forage and removal of porous cup samplers from the field in Vernon, TX 2007-08.


Figure 7. View of rye roots on the porous cup sample at a depth of 3’ in Vernon, TX 2007-08 season.

Following the insertion and initial evacuation of the primer water samples from the slurry, the porous cup were to be evacuated following major (>1”) precipitation events. In 2005-06 and 2007-08 seasons, a major precipitation event did not occur during the winter growing season. Despite the lack of precipitation in these years, an attempt to evacuate water from the porous cup samplers occurred at least twice during the season. See Figures 8, 9, and 10. Additionally, the vacuum pressure was any water samplers were reset to the 30 psi level at these times. In 2006-07, when adequate precipitation occurred in the late winter and early spring and the conditions were favorable to collecting one or multiple water samples, it was discovered that the farmer had applied nitrogen fertilizer over the research trial. Due to this confounding factor, the study was abandoned and the porous cup samplers were removed.

Figure 8. Porous cup sampler (vacuum hose and water sample hose) in the winter wheat cover crop.

Figure 9. Using a vacuum pump to evacuate water samples from the research plots at Vernon, 2007-08.

Figure 10. Using a vacuum pump to evacuate water samples from the research plots at Vernon, 2007-08.

In 2005-06 and 2006-07, multiple soil samples were pulled at 1 ft increments down to 3 ft across the research trial area. These samples were mixed to make a composite sample that would represent the initial soil nitrogen levels for the entire plot. Due to the reasons mentioned above, soil samples were not pulled at the end of the season. In 2007-08, soil samples were taken from each individual plot within the trial at planting and following the cover crop harvest.

All data was analyzed using Fishers Protected LSD at the 0.05 level.

Results and Discussion: In the 2005-06 season, the cover crops did not establish in the fall because of drought conditions during late fall and early winter. The cover crops did emerge in the spring, but the biomass levels were below an accurate measurement level. In the 2006-07 and 2007-08 seasons, the winter cover crops were established in the fall and significant biomass accumulation was obtained. In 2006-07, the shoot biomass was not quantified because the trial was accidently fertilized by the collaborator and this confounded the biomass results.

In 2007-08 season, shoot biomass was the highest with cereal rye (4300 lb/a), followed by wheat (2500 lb/a) and no differences were observed between the vetch (540 lb/a) and the fallow (560 lb/a) treatments. See Figure 11. Using the forage analysis for crude protein and shoot biomass, the amount of nitrogen per acre was calculated for each cover crop. In the fallow plots, some broadleaf and grass weeds were present. The estimated nitrogen per acre recycle was 17 lbs/a, while the vetch treatment was 20 lbs/a. However, the rye and wheat were significantly better at recycling nitrogen because of the large biomass produced. The cereal rye and wheat had accumulated over 110 and 75 lbs/a of nitrogen in their biomass. See Figure 12. Although root weights were not quantified, previous research has shown a 1:1 shoot to root ratio. Using this assumption, total nitrogen recycled and temporarily removed over 150 lbs/a of nitrogen from potentially leaching below 3 ft. and eventually into the groundwater.

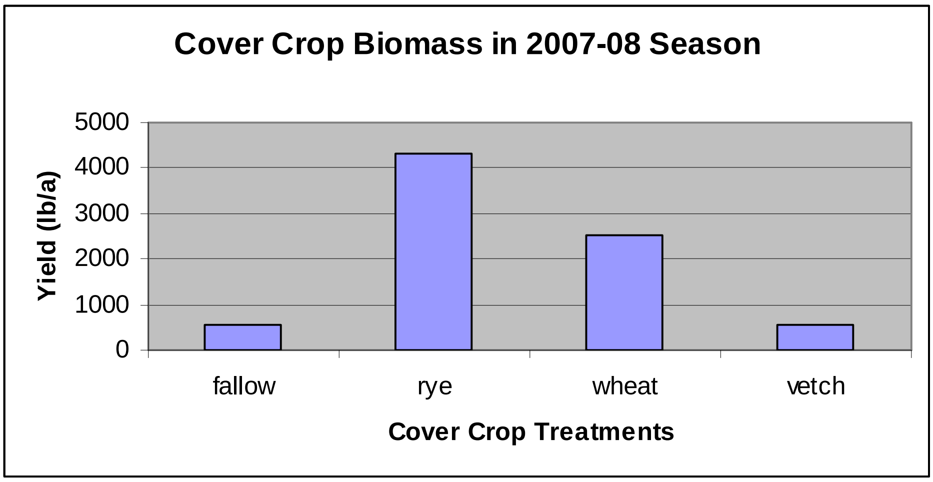


Figure 11. Shoot biomass (lb/a) of each of the cover crop treatments.

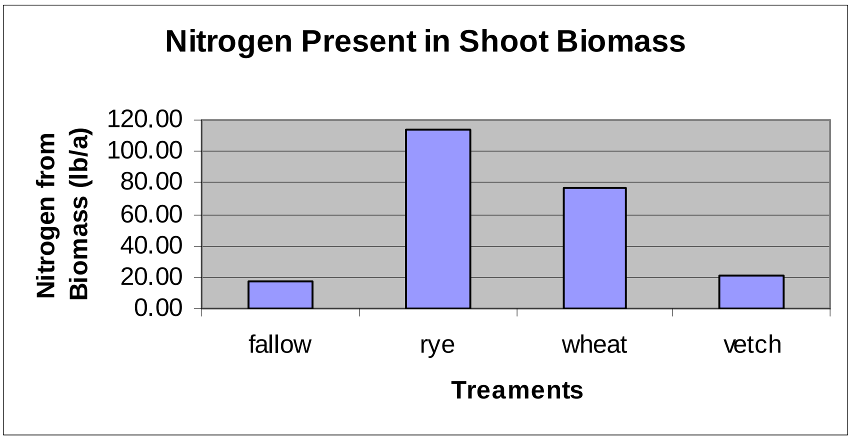


Figure 12. Estimated nitrogen (lb/a) recycled by the winter cover crop treatments. Calculations are based on a shoot biomass and forage analysis of nitrogen content of the shoot.

Soil samples taken at the beginning of the season indicated nitrate levels ranging from 1 to 8 ppm with an average of 2.9 ppm from 0-1'. At the 1-2' sampling depth, the average nitrate level was 4.5 ppm and had a higher range of levels, 1 to 12 ppm. Nitrate levels at the 2-3' depth were higher than the surface sample, but was lower than the 1-2' depth. The nitrate levels at 2-3' depth ranged from 1 to 8 ppm with an average of 3.4 ppm. The level of variability between plots was very surprising considering the field had been uniformly planted and managed in row crops in the past. These results indicate a lot of spatial variability in the soil nitrate levels both horizontally and vertically. These soils were a sand loam soil and the spatial variability was not expected. Post-season soil samples had a similar range of nitrate levels both at the 1-2' and 2-3' depths, but the range was much higher than the preseason samples. The post-season soil samples for the 0-1' depth ranged from 1 to 14 ppm and averaged 9.8 ppm across all treatments.

To determine the change in nitrate levels in the soil profile, the post-season soil nitrate levels were subtracted from the preseason nitrate levels for each one foot increment. The changes in nitrate levels were not significantly different between treatments at the 0 to 1' depths. For all treatments at the 0 to 1' depth, the nitrate levels increased from 20 to 34 lbs/a. See Figure 13. Nitrate levels were significantly different between the covercrop treatments at the 1 to 2' and 2 to 3' depths. At the 1 to 2' depth, the nitrate levels decreased 5 and 13 lbs/a in the vetch and no covercrop treatments, respectively. See Figure 14. Both of these treatments were similar in the amount of shoot biomass and soil coverage present in these treatments. Soil nitrate levels at 1 to 2' depth in the rye and wheat covercrop treatments increased over the duration of the season. At the 2 to 3' soil depth, the nitrate levels increased in all the treatments, except the vetch treatment. See Figure 15.

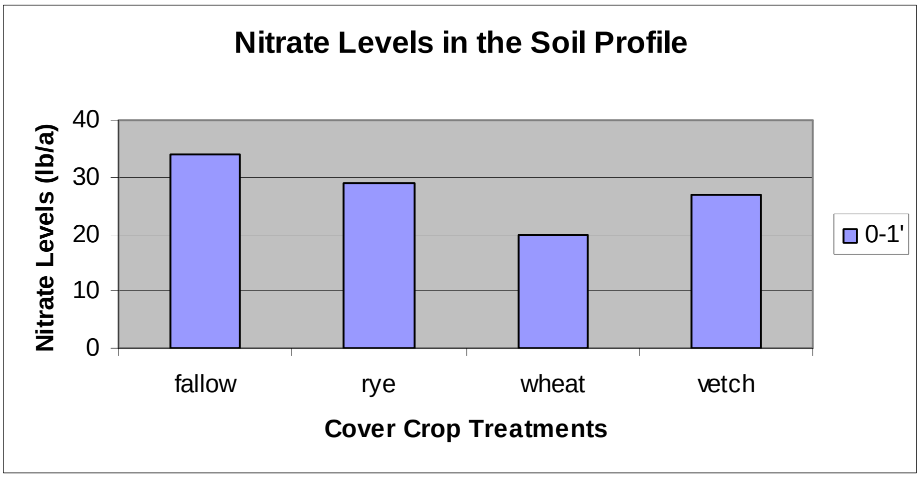


Figure 13. Changes in soil nitrate levels for the 2007-08 season for the 0-1’ depth.

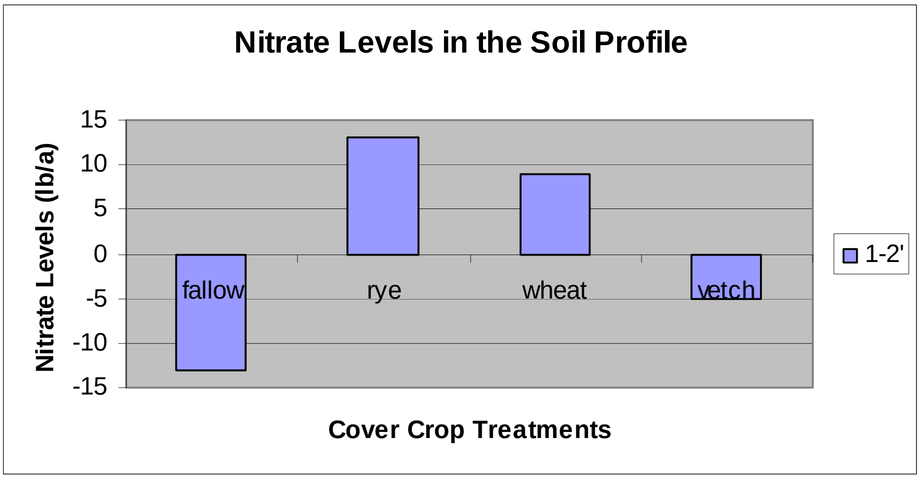


Figure 14. Changes in soil nitrate levels for the 2007-08 season for the 1-2’ depth.

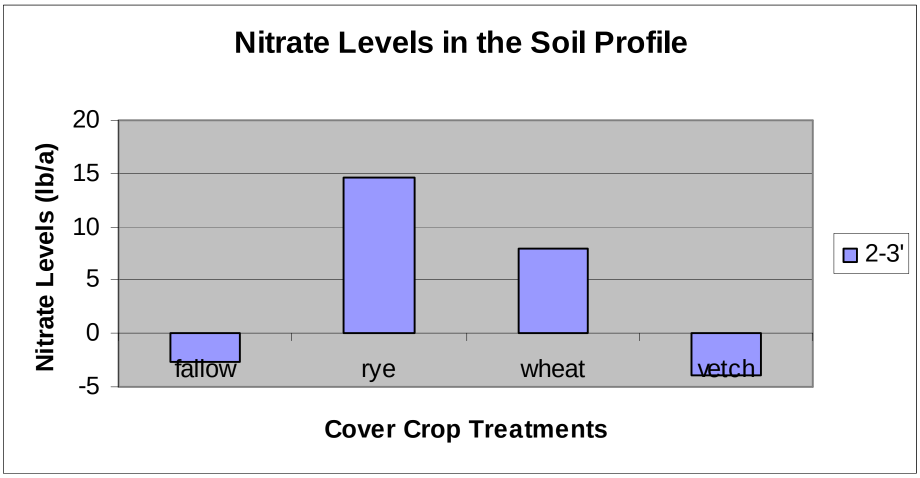


Figure 15. Changes in soil nitrate levels for the 2007-08 season for the 2-3’ depth.

The potential for nitrate leaching was not quantifiable using the porous cup samplers on any of the three years of the experiment. As explained in the first paragraph of the results section, both the 2005-06 and 2007-08 seasons were dry and soils never reached saturation, and no leachate ever accumulated in the porous cup samplers. As mentioned before, the 2006-07 season was compromised due to fertilizer being applied over the plots. Therefore, no results are available from the porous cup samplers.

Conclusions:

Winter cover crops have shown to be a viable option for minimizing nitrate leaching in previous research. However, in the Rolling Plains of Texas, the winter cover crops presented numerous challenges and provided mixed results. First, the winter rye and winter wheat were successfully established in 2 of 3 years. The winter vetch was established in 2 of 3 years, but shoot growth was very limited in both years and was not significantly different than the fallow treatment. The winter cover crop of choice for biomass accumulation would be cereal rye followed by wheat.

Based on the biomass levels for wheat and rye, it is obvious that nitrogen was recycled by the winter cover crops. However, the soil profile samples did not indicate a difference in nitrate levels at the 0-1’ level or the 2-3’ level compared to the fallow. The higher nitrate levels at 1-2’ depth may have resulted from a couple of factors. The first possible explanation is that the wheat and rye cover crops extracted plant available water from the 2 to 3’ depth or deeper. Following this water removal by the cover crop roots, a re-distribution of soil solution from lower depths moved into the 1 to 3’ depths.

Although the impact of cover crops on actual nitrate leaching was not quantified in this study, the importance of the spatial and temporal dynamics of nitrates in the soil profile was established. Additionally, covercrops definitely help to recycle nitrates and other nutrients in this study, but the dynamics of the nitrates masked the many of the benefits of the cover crops.

Future research in the area should consider numerous factors. First, winter cover crops do not appear to be a viable option due to limited soil moisture for establishment and the removal of soil moisture by cover crops will likely hinder cotton or sorghum yields due to increased moisture deficit at planting. Second, vetch does not provide adequate biomass or nitrogen contribution to justify the seed and planting costs.

Task 2: Demonstration of Zeolite as a BMP to Reduce Atrazine and Arsenic in Groundwater

Several planning sessions were held regarding this portion of the project between Dr. Dozier and staff with Texas A&M University Department of Biological and Agricultural Engineering to design a demonstration model to complete this task. Dozier also met with a zeolite manufacturing representative to secure zeolite for the demonstration model. Upon recommendations from the manufacturing representative, the demonstration model was scaled down (due to costs and complexity) to a bench type model. The changes were incorporated into the workplan and was approved by the Texas State Soil and Water Conservation Board (TSSWCB). Even though the demonstration was changed, problems associated with the zeolite portion of this project continued. There was difficulty in securing zeolite and additional changes that would be required to the work plan and QAPP near the end of the project. Based on recommendations from the TSSWCB, the zeolite demonstration was dropped.

Task 3: Assessment of Atrazine and Arsenic Concentrations in Private Water Well Samples of the Texas High and Rolling Plains.

A total of seven water screening events were conducted in Dawson, Haskell, Jack, Palo Pinto, Swisher, Terry, and Wise counties. Water samples were screened to determine the concentrations of atrazine, arsenic, and nitrate-nitrogen in each sample. Samples were also screened for the presence of fecal coliform bacteria.

To determine atrazine concentrations, an immunoassay procedure was employed using Hach equipment and reagents. Procedures were followed as outlined by Hach and results recorded (Table 1).

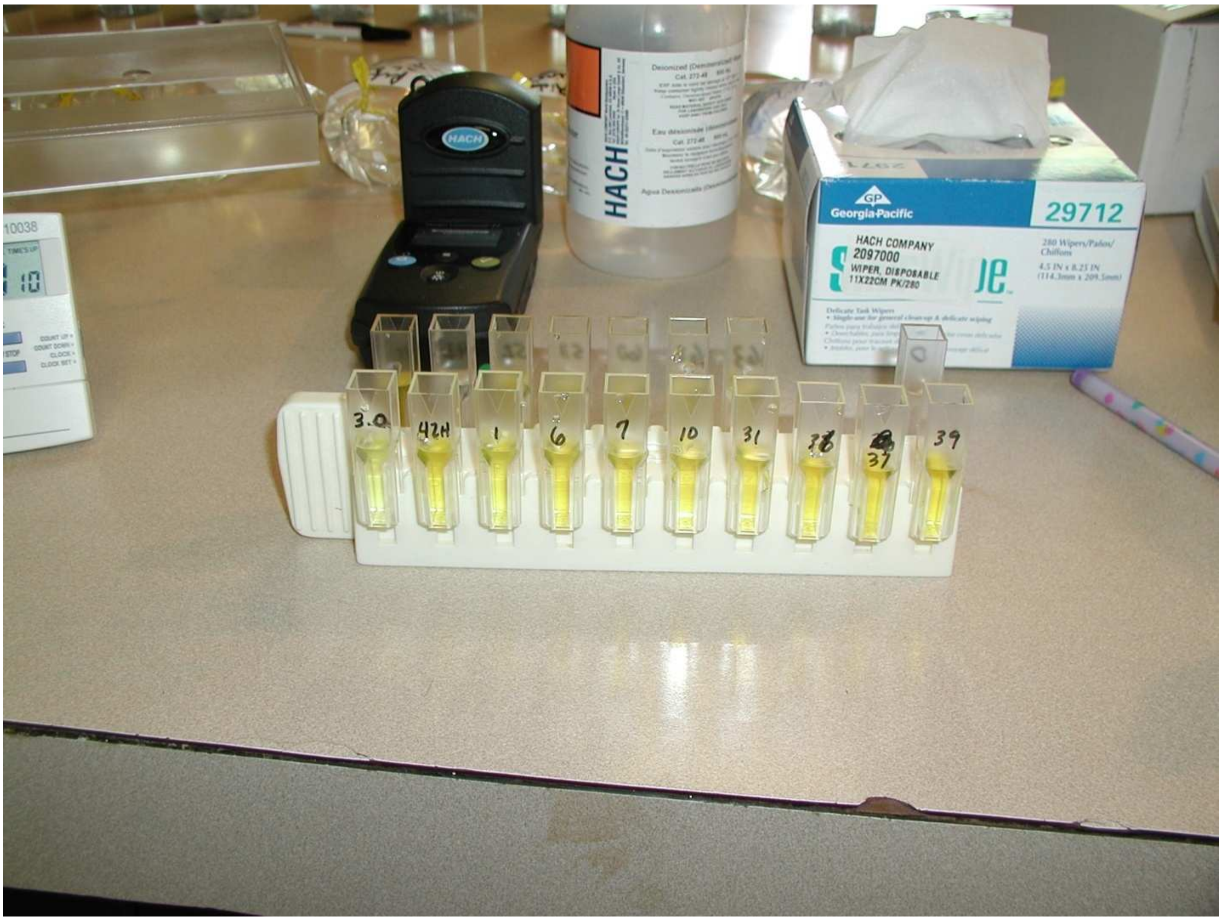


Figure 16. Water well samples prepared for analysis of atrazine concentration using approved Hach pocket colorimeter II (black instrument behind samples) and immunoassay procedure.

Arsenic concentrations in the water well samples were also determined using Hach equipment and methods. The method used employed an arsenic test kit using test strips. Results were determined by comparing test strip color changes to a standardized arsenic concentration color chart. Results are recorded in Table 1. It should be noted that a total of 116 samples were collected and tested for atrazine concentrations and 135 for arsenic concentrations.

Of the 116 samples tested for atrazine, 87 had concentrations that fell in the less than 3.0 μg/L range and four greater than 3.0 μg/L. Additionally, five samples were lost during the extraction process.

Of the 135 samples tested for the presence of arsenic, 104 samples had a concentration of 0.0 μg/L range, 30 had a concentration in the 0.0 to 10.0 μg/L range, one in the 10.0 to 30.0 μg/L range, and one was lost in processing.

Figure 17. Well water samples being screened for arsenic concentrations using approved Hach equipment and procedures.

Nitrate-nitrogen concentrations in the water well samples were also determined using Hach equipment and methods. The method used employed nitrate-nitrogen test strips. Results were determined by comparing test strip color changes to a standardized nitrate-nitrogen concentration color chart. Results are recorded in Table 1. It should be noted that a total of 238 samples were collected and screened for nitrate-nitrogen concentrations. The average nitrate-nitrogen concentration for all samples was 2.7 mg/L.

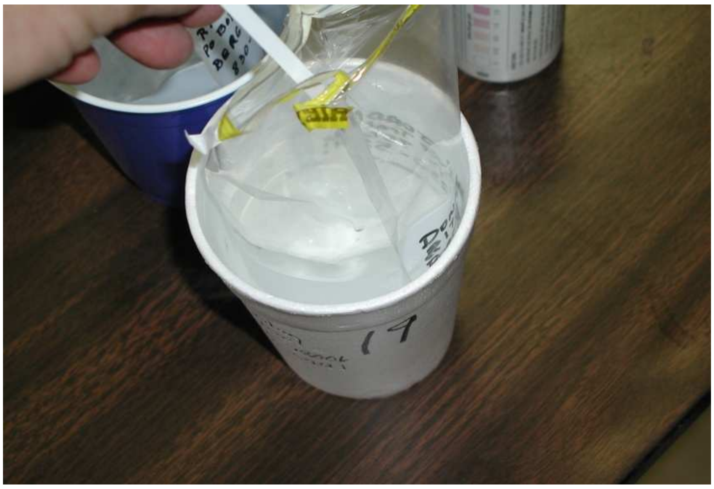


Figure 18. Dipping nitrate test strip into water sample.

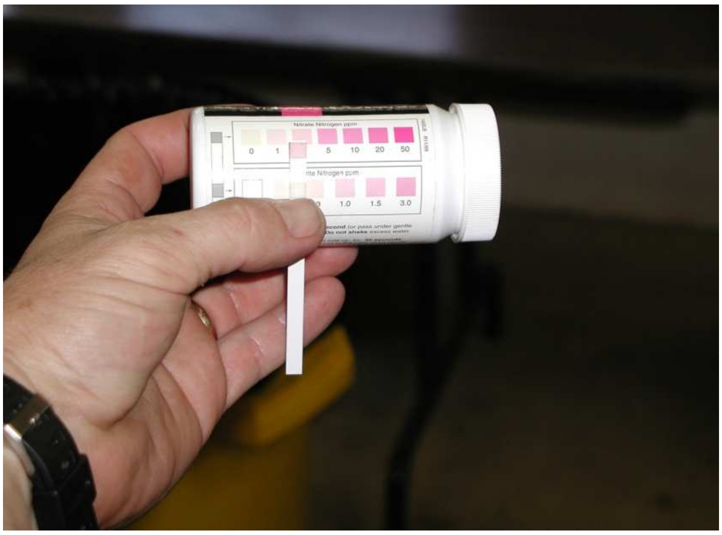


Figure 19. Comparing test strip results to Hach standards for nitrate-nitrogen.

Samples were also tested for salinity concentrations using a conductivity meter. A total of 238 water samples were tested for salinity and the average salinity concentration of all samples was 512.9 mg/L. The complete results are outlined in Table 1.

Finally, all water samples were tested for the presence of fecal coliform. Samples were filtered through a filter and placed in a petri dish with indicator media. Petri dishes were then placed in an incubator and incubated for the prescribed time and at the recommended temperature. Upon completion of the incubation period, all petri dishes were analyzed for formation and growth of fecal coliform colonies. Of the 238 samples tested for the presence of fecal coliform, 92 or 38.7% tested positive for the presence of fecal coliform bacteria. Total number of samples screened and the number and percentage of samples found positive for fecal coliform are outlined in Table 1.

Figure 20. Set up with incubator (1), sterile filters (2), filtering manifold (3), and sterile petri dishes (4). Using this setup allowed for screening water samples on site for bacterial contamination.

Table 1: Results for County Water Screening Events.

Date	County	# As[1]	# Atz[2]	# FC[3], NO_3[4], & TDS[5]	# As 0 µg/L	# As 0-10 µg/L	# As 10-30 µg/L	# Atz 0 – 3 µg/L	# Atz > 3 µg/L	# + FC	% +FC	Ave. NO_3 mg/L	Ave. TDS mg/L
10/25/06	Haskell	25	25	25	15	9	0	2	0	2	8.0	9.3	630
04/13/06	Dawson	12	0	12	5	7	0	na[6]	na	10	83.3	6.3	733
04/14/06	Terry	7	0	7	3	4	0	na	na	4	57.1	4.2	672
06/07/06	Wise	17	17	78	17	0	0	16	1	19	24.4	9.3	399
06/08/06	Jack	15	15	57	14	1	0	14	1	24	42.1	1.4	651
06/29/06	Swisher	42	42	42	33	8	1	40	2	31	73.8	2.7	333
09/12/06	Palo Pinto	17	17	17	17	0	0	17	0	2	11.8	2.0	619
Total		**135**	**116**	**238**	**104**	**29**	**1**	**89**	**4**	**92**	**38.7**	**2.7**	**512.6**

[1] Arsenic
[2] Atrazine
[3] Fecal Coliform bacteria
[4] Nitrate nitrogen
[5] Total Dissolved Solids
[6] na – screening not completed due to problems experienced during process

Referring to Table 1, it is clear to see that across all samples and counties the number one contaminant of concern associated with private well water is contamination by fecal coliform bacteria. The presence of such bacteria could indicate that the water supply could also be contaminated by pathogenic bacteria such as E. coli.

Only one sample or less than 1% had a concentration of 10 µg/L or greater for arsenic. This result puts this sample at or above the USEPA maximum contaminant level (MCL) for arsenic (10 µg/L) for public drinking water supplies. Regarding atrazine, a slight increase in the number of samples at or above the USEPA MCL of 3.0 µg/L for atrazine was noted. Four samples or 3.4% of the total screened for atrazine had results of greater than 3.0 µg/L.

The average nitrate-nitrogen (NO_3-N) levels in Haskell and Wise Counties neared the USEPA MCL for NO_3-N of 10.0 mg/L. However, the average NO3-N concentrations for all samples from all counties remained below the 10.0 MCL level.

The highest salinity levels as reported in total dissolved solids (TDS) and then converted to mg/L were reported in Dawson County followed by Terry County. These two counties along with Jack and Haskell counties had concentrations for salinity above the USEPA MCL for salinity. However, salinity is listed as a secondary contaminant rather than a primary contaminant. This is based on the fact salinity affects that taste, color, or clarity of the water verses having a health affect related to consumption. Fecal coliform, arsenic, atrazine, and nitrate-nitrogen are considered primary contaminants given they may cause an adverse health affect if consumed at levels above the MCL.